COMBINATION OF COMPRESSOR AND PERMANENT MAGNET MOTOR FOR SEWAGE AERATION

The present invention relates to sewage aeration, and in particular to a sewage aeration system including a centrifugal air compressor.

Water treatment plants generate large volumes of sewage sludge. It is necessary to continuously aerate tanks of sewage sludge by delivering compressed air to the sludge in appropriately designed aeration tanks. Currently three different types of air compressors are used, that is positive displacement blowers, single or multi-stage centrifugal radial flow fans, and mixed flow turbo compressors.

Positive displacement blowers have efficiencies of the order of 60%, multi-stage centrifugal fans have efficiencies in the range of 60 to 70%, the efficiency being lower at higher pressures, whereas turbocompressors have efficiencies above 80% when operating in conditions of maximum efficiency, those conditions generally being referred to as the "duty point". Clearly in circumstances where operating conditions can be maintained substantially constant turbocompressors are significantly more efficient that the alternatives.

Turbocompressors have not dominated the sewage aeration market for two main reasons, that is firstly high capital cost as compared to the alternatives, and secondly an inability to maintain high efficiency in applications where widely varying flow rates are demanded. The operators of sewage aeration plant are sensitive to both capital cost and long term operating costs and therefore monitor oxygen demand in treatment plants and reduce the volume of air supplied if a reduced oxygen demand is indicated. This means that in many applications a compressor must be able to be turned down by as much as 50%, that is to deliver anything between 50% and 100% of maximum output.

Turbocompressors can be considered as belonging to one of two general design types, that is variable geometry and fixed geometry designs. In variable geometry designs, the geometry of passageways within the compressor can be varied as the compressor is rotating so as to adjust compressor characteristics to match varying conditions such as speed or load. In contrast, with a fixed geometry design, no geometry adjustments are possible during operation. Given that the efficiency of a conventional turbocompressor as used for sewage aeration reduces rapidly as the

speed of the turbo impeller moves away from the normal duty point speed the approach adopted to enable turndown of a turbocompressor has generally depended upon the use of variable inlet guide vanes upstream of the impeller. A constant speed induction motor drive is coupled to the turbocompressor by a fixed ratio gearbox such that the turbocompressor rotates at a constant speed higher than the motor speed.

In a typical geared turbocompressor assembly driven by an induction motor, energy losses of approximately 7% occur at the motor, 5% at the gearbox, 2% in the system bearings, and 19% in the turbocompressor itself even if the turbocompressor is a complex design including for example both variable inlet and diffuser vanes. The combination of high capital cost, particularly for variable vane turbocompressors, and inefficiencies in the turbocompressor drive train have encouraged the sewage aeration industry to continue to use the relatively inefficient positive displacement and multistage radial flow centrifugal fans.

A turbocompressor is known which is driven by a conventional induction motor operating at six times synchronous speed, the motor being directly coupled to the turbocompressor to avoid the need for a gear box. The motor is controlled by an inverter, turndown being achieved by controlling the frequency of the AC power supplied to the motor by the inverter. This arrangement is advantageous as gear box power losses are avoided, but at the cost of increased power losses arising in the inverter/motor combination.. These losses are substantial however and thus significant power savings cannot be readily achieved.

In induction motors, an alternating current is used to energise a primary winding on one member (usually the stator). A secondary winding on the other member (usually the rotor) carries only current induced by the magnetic field of the primary. In contrast, in a permanent magnet motor, stator windings are supplied from a DC source through power electronic switches of an inverter. The rotor supports permanent magnets. The stator winding switches are switched so as to be conducting at times determined by a controller which in general is responsive to inputs representing a speed command and a measurement of or estimate of rotor position. Interaction between the magnetic fields produced by the permanent magnets and the magnetic fields generated by the stator windings causes the rotor to rotate. It is known that relatively high efficiencies can be achieved with permanent magnet

motors but generally such motors are only used in relatively low power applications. The use of permanent magnet motors has not been considered in sewage aeration applications where typically powers of the order of 300kW are required.

It is an object of the present invention to provide a sewage aeration compressor which obviates or mitigates the problems outlined above.

According to the present invention, there is provided a sewage aeration turbocompressor for continuously delivering air to a sewage sludge treatment plant, comprising a compressor having a housing, an impeller mounted on an impeller shaft within the housing, and an electric motor having an output shaft coupled to and rotating in synchronism with the impeller shaft, the housing defining an axial air inlet extending to the impeller, a diffuser passageway extending radially outwards from the impeller, and a volute extending from the diffuser to an air outlet, wherein the electric motor is a variable speed permanent magnet motor controlled by an inverter, the motor is deigned to drive the compressor at speeds within a range limited by maximum and minimum design speeds, the compressor is a fixed geometry compressor with a vaneless diffuser designed to deliver a pressure rise between the inlet and outlet of not more than 1500 millibar when the motor is driven at the maximum design speed, and the compressor is designed to deliver maximum efficiency when the motor is driven at a speed less than the maximum design speed.

By limiting the duty pressure rise to less than 1500 millibar a very efficient impeller can be designed which in combination with a vaneless diffuser produces a flat efficiency verses flow curves. Such an arrangement is highly efficient over a wide range of motor speeds.

Preferably the pressure rise ranges from 850 to 1200 millibars. Maximum efficiency may be in the range 1000 to 1050 millibars. The impeller design can be optimised to suit the particular application. Similarly the volute can be designed to optimise efficiency given the vaneless nature of the diffuser. Preferably no vanes are provided in the air inlet, again avoiding energy losses across at least some of the range of possible impeller rotational speeds. The diffuser passageway may be a simple annular passageway of uniform width in the axial direction.

The inverter may be controlled by an oxygen demand sensor coupled so as to monitor the oxygen content of sludge in the sludge treatment plant.

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram illustrating components incorporated in an embodiment of the present invention;

Figure 2 is an axial section through a turbocompressor incorporated in the system illustrated in Figure 1;

Figure 3 is a schematic perspective view of an impeller and volute of the turbocompressor shown in Figure 2;

Figure 4 represents the relative efficiencies at variable flow rates of the turbocompressor shown in Figures 2 and 3 and a conventional sewage aeration turbocompressor incorporating diffuser vanes; and

Figure 5 represents the variation of isentropic efficiency with mass flow for the impellor, diffuser and impeller/diffuser combination in a turbocompressor according to the invention.

Referring to Figure 1, the illustrated system comprises a turbocompressor 1 delivering a flow of air represented by line 2 to an aeration vessel 3, the delivered air being for example bubbled through sewage sludge retained in the vessel 3. Typically the output pressure of the turbocompressor will be relatively low, for example 1.2 bar, with a maximum flow rate of for example 11000m^3 per hour.

The turbocompressor 1 is driven by a permanent magnet motor 4 having an output shaft 5 which is directly coupled to an input shaft of the turbocompressor. Thus the motor 4 and turbocompressor 1 rotate in synchronism. An inverter 6 controls the supply of power to the motor 4, the inverter delivering a current in the range of 200 to 480 Amps to produce a useful power output of the order of up to 300kW. The power supplied to the motor 4 by the inverter 6 is controlled by an input 7 to the inverter provided by an oxygen demand sensor 8 which senses the oxygen demand in the vessel 3. Thus if the oxygen demand is above a predetermined maximum threshold, the inverter 6 drives the motor 4 at full speed, that speed equating to the turbocompressor speed which will deliver the maximum volume of air to the vessel 3. When the sensed oxygen demand falls below the threshold, the motor speed is reduced to match the volume of air supplied to the oxygen demand.

Referring to Figures 2 and 3, the structure of the turbocompressor 1 will be described. The turbocompressor comprises a drive shaft 9 which is directly coupled to and rotates in synchronism with the output shaft 5 of the motor 4 (see Figure 1). The turbocompressor shaft 9 is mounted on suitable bearings and supports an impeller 10 having a central hub from which an array of impeller vanes extend. The hub is shown in Figure 2 but is not shown in Figure 3 so as to make it easier to see the shape of the impeller vanes. The impeller extends into a vaneless axial inlet 11 such that when the shaft is rotated the impeller 10 draws air in through that inlet and delivers pressurised air to a diffuser 12 which is in the form of an annular vaneless slot which is of uniform width in the aerial direction and which extends radially outwards from the impeller 10. The diffuser 12 communicates with a volute 13 which in turn is coupled to an air delivery line corresponding to the line 2 of Figure 1. In Figure 3, the radially inner edge of the diffuser 12 is indicated by line 14 and the position of that edge is indicated by numeral 14 in Figure 2.

Turbocompressors having vaneless inlets and diffusers of the general type illustrated in Figures 2 and 3 are known, as are the criteria which apply to the design of for example the impeller vanes so as to deliver a given rate of flow and output pressure for a given impeller speed. The use of such a turbocompressor with a permanent magnet motor to deliver air to an aeration vessel in a sewage plant is not however known. The use of such a turbocompressor in those circumstances does however provide substantial benefit as discussed with reference to Figure 4.

Referring to Figure 4, the line 15 shows the relationship between isentropic efficiency and the percentage of maximum flow for the turbocompressor of Figures 2 and 3. It will be noted that efficiency peaks at around 70% of maximum flow at just above 85% and falls by a few percentage points at 100% of maximum flow. At all times the efficiency is well above 80%. In contrast, the line 16 represents the relationship between isentropic efficiency and percentage maximum flow in a turbocompressor with a vaned diffuser designed to maximise efficiency in a conventional manner, that is by achieving the highest possible efficiency over a relatively narrow range of impeller speeds. The line 16 indicates a maximum efficiency of 87%, the efficiency falling off with increasing flow to 82% but decreasing very rapidly with decreasing flow.

The results represented in figure 4 are significantly better than what can be achieved with alternative sewage aeration systems. This is summarised in the table below, where row 1 represents a direct drive, permanent magnet motor and high efficiency vaneless diffuser compressor combination in accordance with the invention, row 2 represents a gear ox, induction motor and variable vane diffuser combination, row 3 represents a direct drive induction motor vaneless diffuser combination, and row 4 represents a positive displacement belt driven blower, the table showing for each of the four alternatives the efficiency of the gas compression device (compressor or blower), the drive (motor and drive train), and the combination of the gas compression and drive systems (total) for both duty (100% of maximum speed) and 40% turndown (60% of maximum speed);

EFFICIENCY						
	Duty			40% Turndown		
	Gas	Drive	Total	Gas	Drive	Total
1	85	97	82	82	95	78
2	87	89	77	77	86	66
3	80	92	74	78	88	69
4	63	88	55	59	86	51

As represented in the above table, whereas induction motor/gearbox and induction motor/inverter drives have efficiency losses of approximately 11% and 8% ,at duty flow, respectively the drive system incorporating a 300kW permanent magnet motor in accordance with the invention shows drive losses of approximately 3%. Overall efficiency is approximately 82%. This remarkable efficiency is maintained over the full duty range, that is for all flows and absorbed powers that are contemplated.

Given that in a sewage treatment plant there can be prolonged periods during which a relatively low percentage maximum flow such as 50% is required, the rapid fall off in efficiency with reducing maximum flow percentage indicated by line 16 can result in poor overall efficiency. Thus, combining a high efficiency variable speed

motor such a permanent magnet motor coupled directly to the driveshaft of a turbo generator with vaneless inlet and vaneless diffuser results in an overall increase in efficiency which significantly reduces the overall cost of the system, particularly given that a vaneless turbocompressor is relatively easy to manufacture and maintain. Overall efficiencies of greater than 80% can be achieved. This compares with alternative turbocompressor systems delivering at most approximately 69% efficiency at full turndown. Given current costs of electricity this efficiency difference translates into a cost of ownership saving of the order of £20,000 per year assuming the system delivers on average a gas compression power of 234kW. Compared with an inverter driven positive displacement blower a solution where the total efficiency will be at most of the order of 51%, the annual saving is approximately £75,000. Although the initial cost of a positive displacement blower is lower than a turbocompressor system in accordance with the invention, the running cost savings should be sufficient to cover the increase in cost in a relatively short time, for example less than two years.

Thus, whereas in the prior art turbocompressor systems applied to sewage aeration relied upon fixed speed motors and a gearbox, supplemented by variable vane structures, the motor, turbocompressor and gearbox losses are such that high overall efficiencies cannot be achieved. In contrast, the described embodiment of the present invention relies upon a high efficiency motor, and a very efficient impeller/vaneless diffuser compressor delivering a high efficiency across a wide range of compressor speeds. The variable speed drive motor does require an inverter for motor control, but energy losses in the inverter are relatively small, enabling an overall efficiency significantly better than any of the other alternatives, particularly if the turbocompressor is designed to deliver a relatively low pressure flow of air which is what is required in most sewage aeration applications.